TechData Sheet

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Passive Bioventing in Stratified Soils and Shallow Groundwater Conditions

TECHNOLOGY DESCRIPTION

What is bioventing?

Bioventing is an efficient, cost-effective, and proven in-situ biological treatment technology for unsaturated soils containing contaminants amenable to aerobic biodegradation, and has been applied at numerous Department of Defense installations in the United States and worldwide.

Bioventing technology is used to remove contaminants from vadose-zone soils by providing oxygen to natural, aerobic microorganisms that break down these contaminants.

Bioventing has widespread application potential since soil microorganisms are capable of degrading most petroleum products (e.g., gasoline, jet- propulsion fuel, diesel fuel, heating oils, etc.) under aerobic conditions. Bioventing technology also has a particular advantage for soils contaminated with less volatile fuels since technologies that depend on volatilization, such as vapor extraction, are not very effective at degrading these fuels.

What is "passive" bioventing?

As conventionally applied, bioventing requires a blower to either inject or extract air. However, gases moving naturally in and out of the vadose zone have been observed at several sites. This natural movement of gases is due to barometric pressure fluctuations over time, and provides enough oxygen for biodegradation.

During times of increasing barometric pressure, a negative pressure gradient is developed between the atmosphere and the subsurface, and is measurable as a vacuum at subsurface monitoring points (Figure 1). Airflow can occur at the subsurface if vent wells or monitoring wells are installed and appropriately screened at depths where significant gradients are developed. The reverse effect occurs during times of decreasing barometric pressure (i.e., positive pressure gradients are developed and air flows out of the well).

The magnitude of the pressure gradient (and also the magnitude of the airflow rate) is primarily a function of:

- Rate and magnitude of barometric pressure change
- Depth

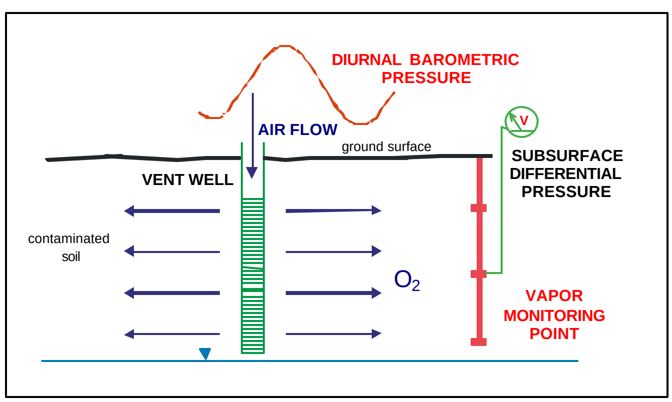

Figure 1. Passive Bioventing process schematic. As barometric pressure increases, a negative differential pressure (vacuum) is induced in the subsurface. This relative vacuum creates a potential for air flow into contaminated soil, promoting biodegradation of contaminants.

- Soil air permeability
- Soil porosity

The benefits of a passive approach are:

- Significantly simpler design
- Can be used at remote sites where power is unavailable or cost-prohibitive
- Reduced O&M
- Less facility disruption
- Increased reliability

Why stratified soils and shallow groundwater?

Previous demonstrations have been primarily performed at sites with deep vadose zones (e.g., groundwater table at 100 feet or more below ground surface (bgs)), where it is intuitive that pressure gradients with depth could be achieved. Although passive bioventing should theoretically work at sites with shallower groundwater and a stratified lithology, where pressure gradients would exist due to significant vertical variation in air permeability and porosity, it had never been demonstrated prior to the demonstration at Castle Airport located in central California.

SITE DESCRIPTION

The site, located at Castle Airport (formerly Castle AFB) in California's Central Valley, is a former Petroleum, Oils, and Lubricants (POL) fuel farm built in the 1940's and was the bulk fuel storage and distribution facility for the base. Conventional bioventing was selected during the feasibility study as the preferred remedial option for the site.

Figure 2 shows the passive bioventing demonstration layout in plan view. The initial phase of the demonstration consisted of installing one vent well (VW) and eight vapor monitoring points (VMP) containing an oxygen sensor and pressure measurement port (Photos 1,2, and 3). Two VMPs (VMP-14 and VMP-15) previously existed at the site. The VW was screened between 25 and 65 feet bgs, below the near-surface silty sand and clay/silt layer (see Figure 3). A total of eight VMPs, consisting of two radial arms each, with four VMPs, were installed adjacent to the VW. The four VMPs along each arm were located at distances of 4, 8, 12, and 16 feet from the VW to evaluate changes in oxygen concentration (Photo 4). To allow for multi-depth monitoring, each VMP is constructed with an isolated, depth-discrete screen.

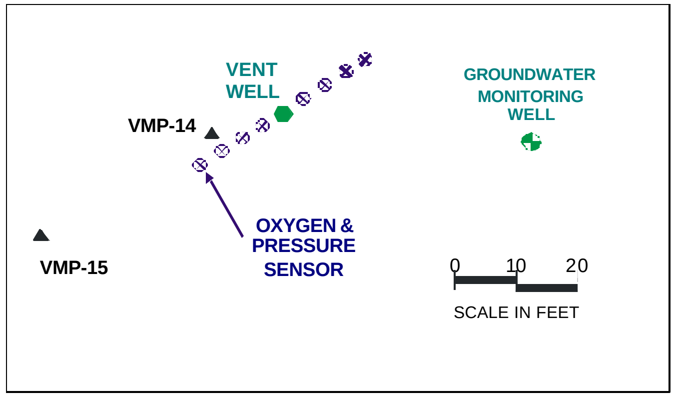

Figure 2. Plan view of demonstration test area. Directly-buried oxygen sensors with an integrated pressure measurement ports were located at 4, 8, 12, and 16 feet from the vent well. Depths were 10, 30, 45, and 60 feet below ground surface. Conventional vapor monitoring points (VMP) were also used.

Photo 1. Oxygen/pressure sensors strapped to 2-inch PVC casing prior ro installation. Black wire is oxygen data line; yellow tubing provides soil vapor sampling and pressure measurement port.

Photo 2. Surface completion of oxygen/pressure sensor.

Photo 3. Installation of oxygen/pressure sensors using hollow-stem auger.

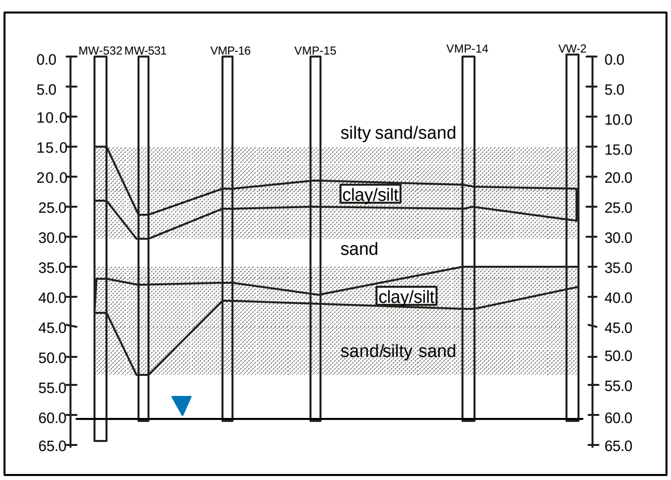

Figure 3. Generalized geologic cross-section. Note the continuous stratification of the soil across the site. Plan view locations of VW02, VMP14, and VMP15 are shown in Figure 2.

Photo 4. Site plan showing vent wells, sensors, and data logger (See Figure 2).

Geology

Figure 3 shows a generalized cross-section of the test area. The site has a stratified lithology and a groundwater depth of approximately 60 feet bgs. The shallow subsurface stratigraphy is characterized by alluvial deposits consisting of interbedded sequences of clays, silts, sands, and gravels. The upper 20 feet is predominantly silty sand, overlying a laterally continuous clay/silt layer between approximately 20 and 25 feet bgs. Between 25 and 35 feet bgs the layer is predominantly sand with little to no fines. Another continuous clay/silt layer approximately 5 to 10 feet underlies this sand. Below this second clay/silt layer is sand extending to the groundwater table.

Contaminants/Physical Soil Properties

Maximum contaminant concentrations in soil are:

- 28,000 mg/kg total petroleum hydrocarbons (as gasoline)
- 12 mg/kg benzene
- 293 mg/kg total BTEX
- 18 mg/kg naphthalene

Contaminant concentrations are generally higher below 25 feet bgs; consistent with the site conceptual model that vadose zone contamination resulted from a declining groundwater table which created a smear zone of contaminants.

The average moisture content of the near-surface silt and silty sands is 15.8 percent, while the average moisture content of coarser-grained materials, generally found below 35 feet bgs, is 7 percent. Moisture content generally correlates with grain-size, with a higher moisture content being measured in finer-grained materials (silts and silty sands).

Oxygen Concentrations

Oxygen concentrations in soil vapor are generally less than 1 percent in the contaminated areas while concentrations in the background soil vapor are above 19 percent, indicating very little natural oxygen demand in the soil. This measured oxygen-depletion in the contaminated soil is indicative of microbial activity and indicates that microbial growth is currently oxygen-limited.

METHODOLOGY

A real-time data acquisition system (Photo 5) was installed to continuously monitor barometric pressure, subsurface oxygen concentrations, differential pressure, and airflow rates. A directly- buried oxygen sensor with an integrated sampling and pressure measurement port was installed at each of the 24 monitoring points/depths. Bidirectional pressure transmitters were used to measure subsurface differential pressure at each location and a K-type thermocouple was used to measure ambient temperature. An airflow transducer was installed at the surface to measure airflow into and out of the vent well. Every 10 minutes the data acquisition system, which had an integrated barometric sensor, collected and stored all the measurements.

A one-way, passive valve was constructed and used during testing to enhance the potential treatment radius (Figure 4 and Photo 6). The one-way, passive valve allows air to enter the VW only when pressure in the subsurface is lower than atmospheric pressure (a negative differential pressure). When the reverse gradient occurs, the valve closes to prevent the exhalation of previously injected air.

Photo 5. Modular data logger system.

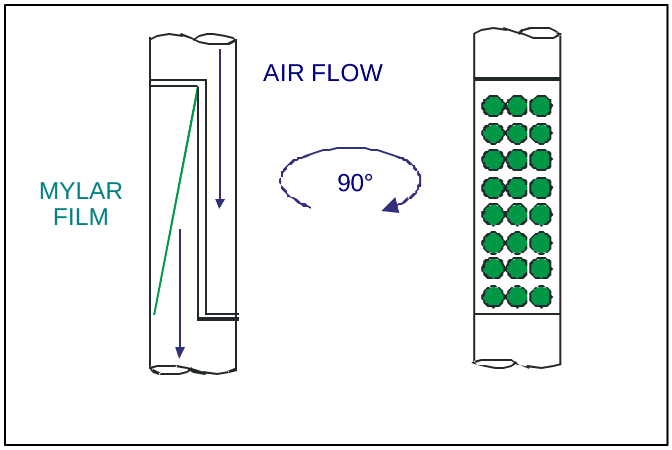

Figure 4. One-way passive valve. This valve is used to allow air to flow in only one direction (in this case, into the vent well). It prevents the exhalation of previously injected air and enhances the treatment radius.

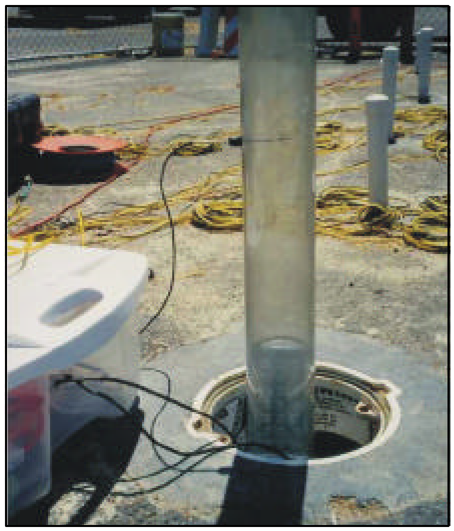

Photo 6. Airflow transducer and one-way passive valve installed at vent well (See Figure 4).

Every 10 minutes the data acquisition system collected and stored the following data:

- Barometric pressure
- Airflow rate at the VW
- Differential pressure at each VMP
- Oxygen concentration at each VMP
- Ambient air temperature
- Groundwater elevation

A series of tests were conducted at the site. A summary of these tests is provided:

- Test 1: VW closed (no air flow; control test)
- Test 2: VW open without passive valve installed
- Test 3: VW closed (equilibrium/respiration)
- Test 4: VW open with passive valve installed in injection mode

Test 1 was designed to evaluate the effects of barometric pressure fluctuations on subsurface oxygen and pressure conditions without any system enhancement. Test 2 was designed to evaluate subsurface oxygen response and air flow rates both into and out of the VW without the use of a one- way valve. Test 3 was required to allow the system to reach equilibrium between Test 2 and Test 4, and was also used to measure microbial respiration rates and potential biodegradation rates. Test 4 was the primary test for the passive bioventing demonstration and evaluated the effect of the one-way valve.

RESULTS

The differential pressure is negative during periods of increasing barometric pressure and positive during periods of decreasing barometric pressure. The magnitude of the subsurface differential pressure is significantly greater at 30 feet bgs compared to 10 feet bgs. However, the magnitude of the response at 30 feet bgs was essentially identical to that at 45 and 60 feet bgs in all VMPs. Therefore, the significant influence on subsurface differential pressure factor at this site is not depth, but rather the geological stratification, more specifically, the overlying lower permeability silty sand between 0-foot and 20 feet bgs and the clay/silt layer between 20 and 25 feet bgs (Figure 3).

Test 2 was conducted in mid to late June 1998 when the VW was open to the atmosphere, but air was allowed to flow both into and out of the well (i.e., without a one-way valve installed). Figure 6 shows a relatively significant weather front-related barometric pressure change during the first three days of the test, followed by diurnal barometric pressure changes. Both the weather-front and diurnal barometric pressure changes resulted in significant airflow rates both into and out of the VW. Airflow rates as high as 20 cfm occurred during the weather front changes and were as high as 12 cfm during diurnal changes. These airflow rates are comparable to typical airflow rates used during conventional bioventing and clearly demonstrate the feasibility of using a passive bioventing approach at this site.

Test 2 with the VW open to the atmosphere and air was allowed to flow both into and out of the well (i.e., without a one-way valve installed). In contrast Test 4 with the VW open to the atmosphere, but air was only allowed to flow into the well (i.e., with a one-way valve installed). The data clearly shows that the one-way valve significantly increased the treatment radius, defined as the distance from the VW where oxygen concentrations remain above 5 percent (available oxygen is generally considered to limit microbial growth at concentrations less than 5 percent).

During Test 4, there is a progressive increase in the time for the oxygen response to occur related to the distance from the injection point. However, within a relatively short period of time, oxygen concentrations increased from less than 1 percent to greater than 15 percent at each VMP. Also, long term air injection from the VW showed increases in oxygen concentration of 5 percent as far away as 40 feet from the VW (as measured at the conventional bioventing VMP-15 shown in Figure 2).

There is a strong correlation between the two parameters, as expected, due to Darcy's Law. However, since differential pressure is easier to measure than airflow, this relationship, if predictable at a site, would provide a relatively inexpensive way to screen sites for passive bioventing potential.

COST PERFORMANCE

A cost curve could be developed based on the treatment radius from both a passive and conventional approach at each site. The breakeven point is the point at which the cost to install any additional VWs under a passive bioventing approach is equal to the additional blower capital and O&M costs under a conventional bioventing approach. Cost curves will necessarily be site-specific since they are dependent on electrical installation cost, electrical operation costs, contaminated soil volume, and treatment radius. However, in order for passive bioventing to be cost effective, it is not a requirement that the treatment radius equal that of conventional bioventing.

CONCLUSIONS/FUTURE WORK

- Geology is as important as depth
- Differential pressure and permeability/moisture are better screening indicators than barometric pressure change
- Passive valve substantially increased treatment radius
- Under the right conditions passive bioventing can be cost effective
- Goals: Cost effective site screening mechanisms
- Looking for additional sites with following characteristics:
  - Change in barometric pressure > 0.10 ”Hg
  - Change in ambient temperature > 25 of
  - Stratified soils/shallow groundwater
  - Midwestern and eastern US

For more information on
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